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Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

ENERGY & ENVIRONMENT DIVISION

ENERGY EFFICIENT WINDOWS PROGRAM

Chapter from the Energy and Environment Division
Annual Report 1979

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ENERGY EFFICIENT WINDOWS PROGRAM

ANNUAL REPORT 1979

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Energy & Environment Division
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ENERGY EFFICIENT WINDOWS PROGRAM

S. Berman, R. Johnson, J. Klems, M. Rubin, S. Selkowitz, and R. Verderber

INTRODUCTION

Approximately 20% of the annual energy consumption in the United States is used for space conditioning of residential and commercial buildings, and about 25% of that figure is required to offset heat loss and gain from windows. In other words, 5% of national energy consumption, 3.5 quads annually, or the equivalent of 1.7 million barrels of oil per day, is tied to the thermal performance of windows.

An important aim of the Windows Program is to develop and commercialize innovative and effective window designs, materials and accessories that support national energy conservation goals. Of critical importance to our program is that design professionals and the public-at-large recognize, accept and use these products. To that purpose, we have developed a broad-scale program encompassing research and development activities, field demonstrations, market studies and an education and public information program. While the technical management of these projects is the responsibility of the Windows Group, certain portions of the work are subcontracted out.

ACCOMPLISHMENTS DURING 1979

The work accomplished in FY 1979 comprises three major areas: (1) program planning and management, (2) performance testing and analysis, and (3) design strategies, materials, and prototype developments. Projected activity for 1980 is included in the detail presented below.

Program Planning and Management

The Windows Program Plan is being developed to outline and coordinate all DOE-supported energy conservation activities related to windows, and will interface with the DOE Thermal Envelopes and Insulating Materials Program Plan and the Passive Solar Program Plan. Substantial efforts were made in 1979 to better coordinate with the DOE Passive Solar Program to avoid unnecessary duplication of effort. As a result of this activity, several joint programs are in progress or under discussion.

In our continuing concern that research activities have commercial potential and applicability, we have looked in detail at several subsectors of the window accessories market to understand the relationships between product manufacturers and the distribution and sales networks that provide building designers and managers as well as homeowners with product selections. Our immediate next concern is that technical data and non-technical information on energy-conserving window designs be readily transmitted to relevant professionals. To this end, we developed a publication, "Windows for Energy-Efficient Buildings," which reports on latest developments, patents, new materials and products, legislation, etc., and is circulated widely to architects, engineers, manufacturers, inventors, suppliers, code officials, and researchers. In the process of generating material for this publication, extensive product files, patent files, bibliographies and related information resources have been compiled.

Performance Testing and Analysis

Thermal Performance Testing. We have set up a Building Technology Laboratory in the College of Environmental Design of the University of California, Berkeley, to support our research and development activities, to provide independent tests and evaluations of materials and products submitted by subcontractors, and to permit evaluation of new products being introduced to the market. Testing facilities include a calibrated hot box (shown in Fig. 1), which is now being used to test the thermal performance of

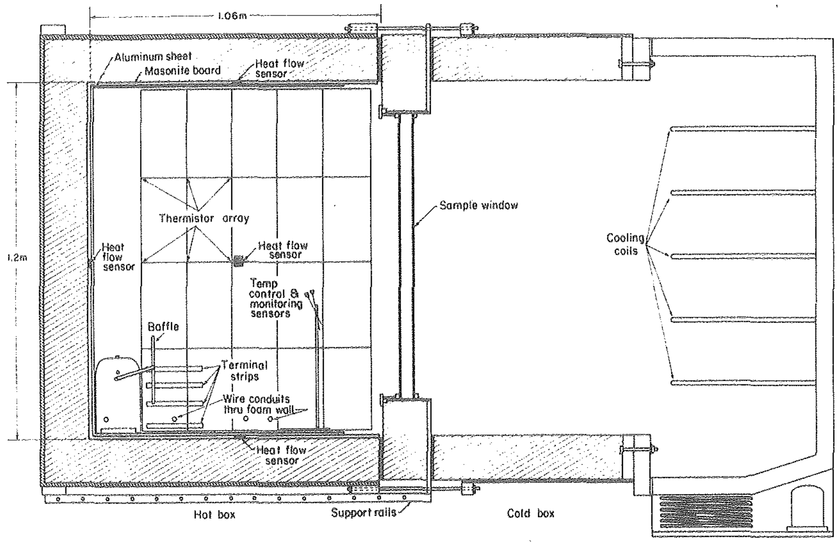

Fig. 1. Section through calibrated hot box showing hot and cold box chambers and sample window. (XBL 799-2921)

windows and associated energy-conserving accessories. Sample results are shown in Fig. 2. Infiltration tests on windows can now be made in our laboratory with the apparatus shown in Fig. 3. The heat loss and heat gain rate of windows can be improved with the use of thin-film coatings on glazing materials. We now have capabilities for measuring a range of optical properties of glazing materials and coatings, and additional measurement capabilities will be added in 1980. A solar calorimeter for measuring the solar heat-gain properties of windows is under construction and should be completed in FY 1980.

A major goal of our program is to develop and promote managed window systems, i.e., windows whose thermal/optical properties can be manually or automatically changed by building occupants. The laboratory testing facilities described above were designed primarily to conduct steady-state measurements of static materials and devices. Accordingly, we are designing a Mobile Window Thermal Test (MoWITT) facility to test the performance of managed window systems (see Fig. 4). As conceived, such a facility will permit the testing of net thermal performance of windows (combined infiltration, conduction/convection, radiation effects) as a function of window orientation and changing weather conditions throughout the day. Winter testing will be conducted in a cold, mountainous location and summer testing in a desert area. The thermal properties of each of the four test chambers in the MoWITT facility can be varied in terms of insulation level, thermal mass, and air-leakage rate, enabling us to simulate a wide range of building conditions. From these experimental results, we will be able to rank the performance of various window-management strategies as well as validate our analytical models. Working drawings for the MoWITT facility are nearing completion, and construction is scheduled for late 1980. Development of software for its data-acquisition system is in progress.

Analysis and Computer Modeling. A detailed analytical model of the net heat transfer through a window assembly composed of an array of glazing elements and optical coatings was also developed this year. This model will also predict the performance of multiple-glazed windows in which the airspace has been filled with a low-conductivity gas. Additional capabilities will be added in the coming year.

A computer model for calculating optical constants for a variety of multilayer optical films was also completed. We calculated the spectral properties of various coatings in order to generate optical coefficients for analysis of visible and solar radiation transmission through windows, as well as thermal transfer between glazing layers.

In order to determine the effectiveness of window-management strategies, the performance of the window must be assessed in the context of the performance of the entire building. For these studies, we have used the Building Energy Analysis Program (DOE-2), modified to incorporate a variety of window management strategies such as movable shades and shutters and to provide detailed quantitative information on the hourly performance of windows and a more qualitative graphic perspective of the net gains and losses of windows on an hour-by-hour basis over the year. The performance of a variety of movable insulating devices for windows has been calculated by means of this model. Figure 5 shows the annual heating loads of a house in

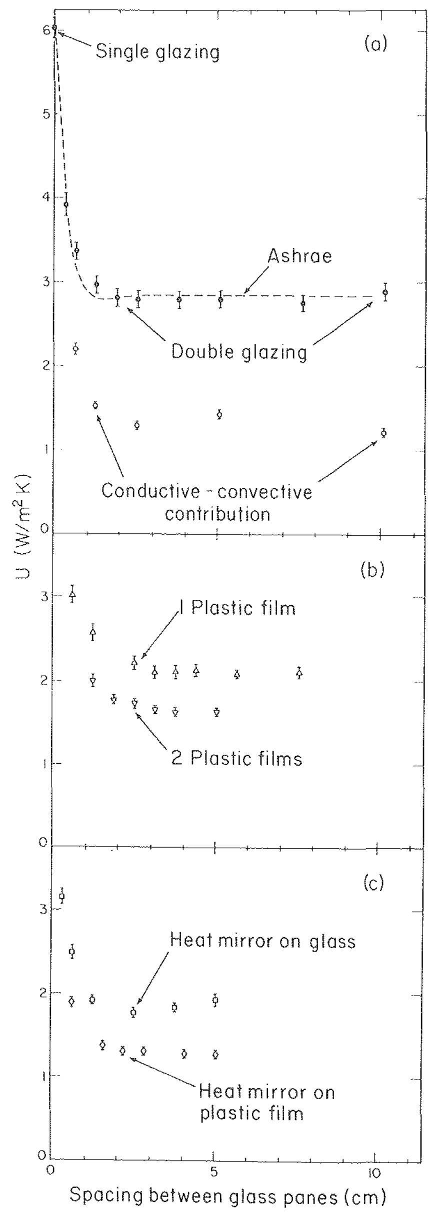

Fig. 2. Sample Thermal Transmittance vs. Glass Spacing for the Prototype Windows. (XBL 799-2917A)

a) Ordinary double glazing (solid points) and double glazing with aluminum foil on inside of both glass panes (open circles).

b) Double glazing with one (triangles) or two (inverted triangles) plastic films.

c) Double glazing with heat mirror coating on plastic film, where the plastic film is mounted on the surface of one glass pane (squares) or suspended between panes (diamonds).

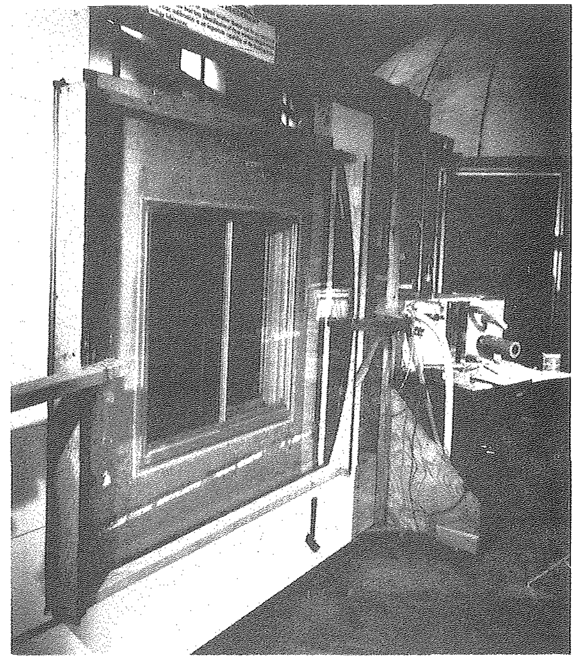

Fig. 3. View of apparatus for measuring air leakage of windows. (CBB 793-3731)

Minneapolis whose single- and double-glazed windows were fitted with a variety of insulating coverings that were closed for 12 hours each night. The effects of window orientation, window area, hours of operation and air-leakage characteristics of the window coverings may be just as important as the insulating value in determining annual energy savings. The foregoing studies are concerned with winter performance; in FY 1980, we will extend this work to include the effect of movable shading devices on cooling loads.

Design Strategies, Materials, Prototype Developments

Daylighting. Windows and skylights provide visible daylight in buildings, thus reducing lighting energy and peak power requirements. In addition, natural lighting has always been valued by architects and building occupants for qualitative reasons. In FY 1979, our daylighting program activities were significantly expanded.

In order to predict annual energy savings, data on daylight availability (including the frequency and intensity of daylight) must be collected. No source for such data currently

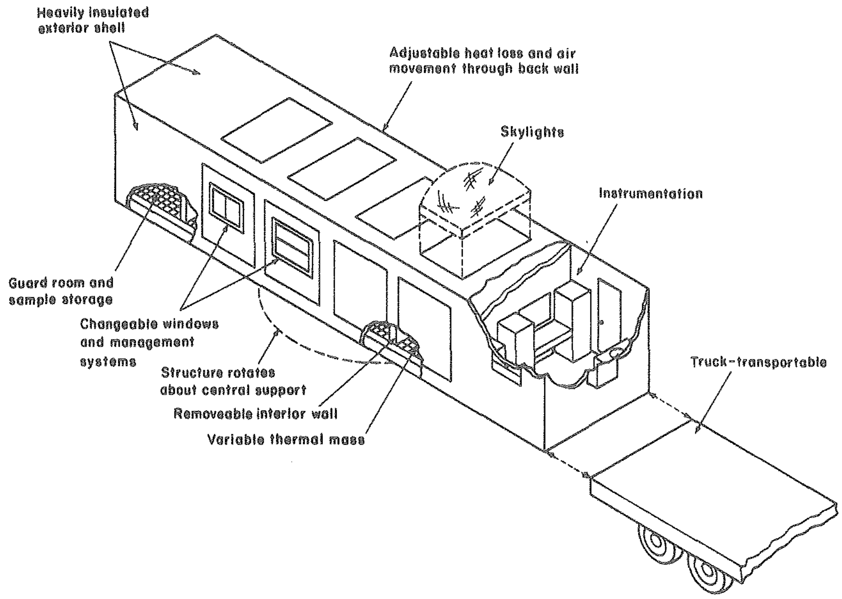

Fig. 4. Schematic view of Mobile Window Thermal Test (MoWITT) facility. (XBL 796-1848)

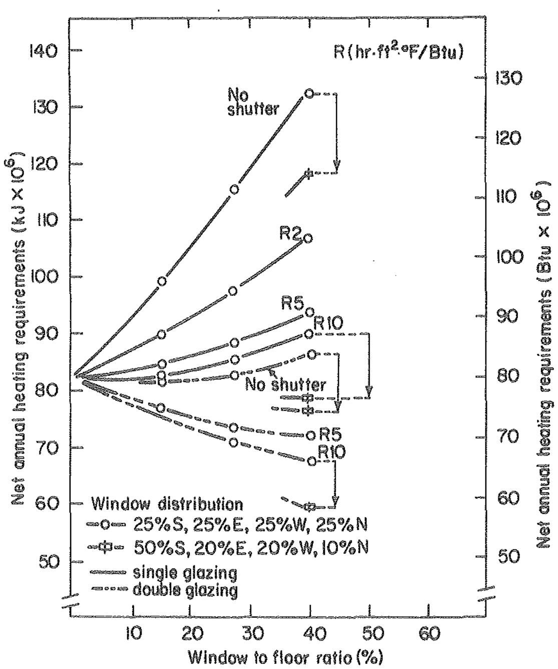

Fig. 5. Annual heating energy requirements for a house in Minneapolis based upon various glazing and insulating shutter options. (XBL 796-10097)

exists for most of the United States. The Pacific Gas & Electric Company Building in San Francisco has been instrumented to collect and record the amount of solar and visible radiation available at all building surfaces. An array of thirteen pyranometers and photometers has been installed to feed readings to a data-acquisition system at fifteen-minute intervals (see Fig. 6). Preliminary results for the first year of monitoring suggest strong linear correlations between illumination and insolation -- a finding which encourages us to believe that daylight availability data can be generated from existing measurements of solar radiation. A generalized method for developing illumination availability data from insolation is being developed.

Accurate and efficient daylighting design methods must be conveyed to building designers if they are to successfully incorporate daylighting designs in buildings. Three different approaches are in progress as part of the overall LBL program in this area: Under subcontract, Renssallear Polytechnic Institute is developing a computer program to predict daylight illumination in interior spaces; a team at the University of Washington is developing a graphic design method which employs transparent overlays for daylight predictions; and, finally, an LBL project is underway to simplify design techniques (computational and graphic) for predicting daylight illumination from clear and overcast skies (Fig. 7). Activity in these

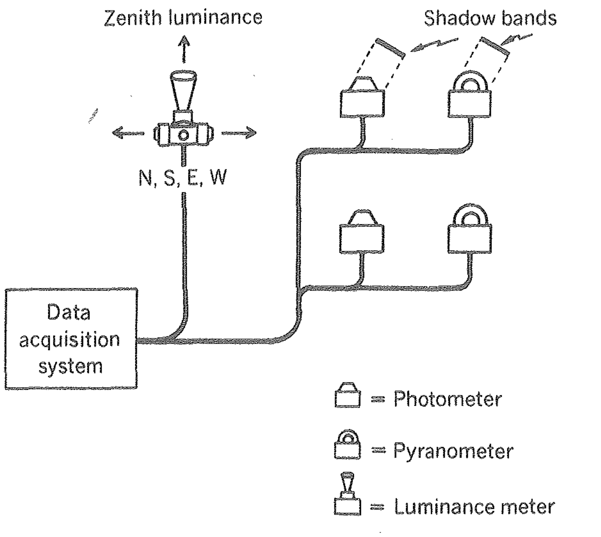

Fig. 6. Schematic of rooftop photometric and radiosensor array for determining insolation/illumination correlations. (XBL 796-10182)

areas will continue in 1980 and a small effort to add daylighting analysis capabilities to a building energy analysis program (DOE-2) will be expanded.

Physical models are useful for studying alternative daylighting systems. To facilitate these studies, an artificial sky dome has been designed and built on the U.C. campus (Fig. 8). Luminance distributions for both clear and overcast skies will be reproduced on the underside of the hemisphere; by measuring light levels in a scale model building under this "artificial sky," we will be able to predict actual values expected in a real building. The addition of the lighting control system and an associated photometric measurement system in 1980 will make the artificial sky fully operational.

Direct sunlight is the only natural light source with sufficient intensity and collimation to illuminate interior spaces deep in the building, and various design approaches have been studied to exploit beam daylighting in buildings. Over the past two years we have examined

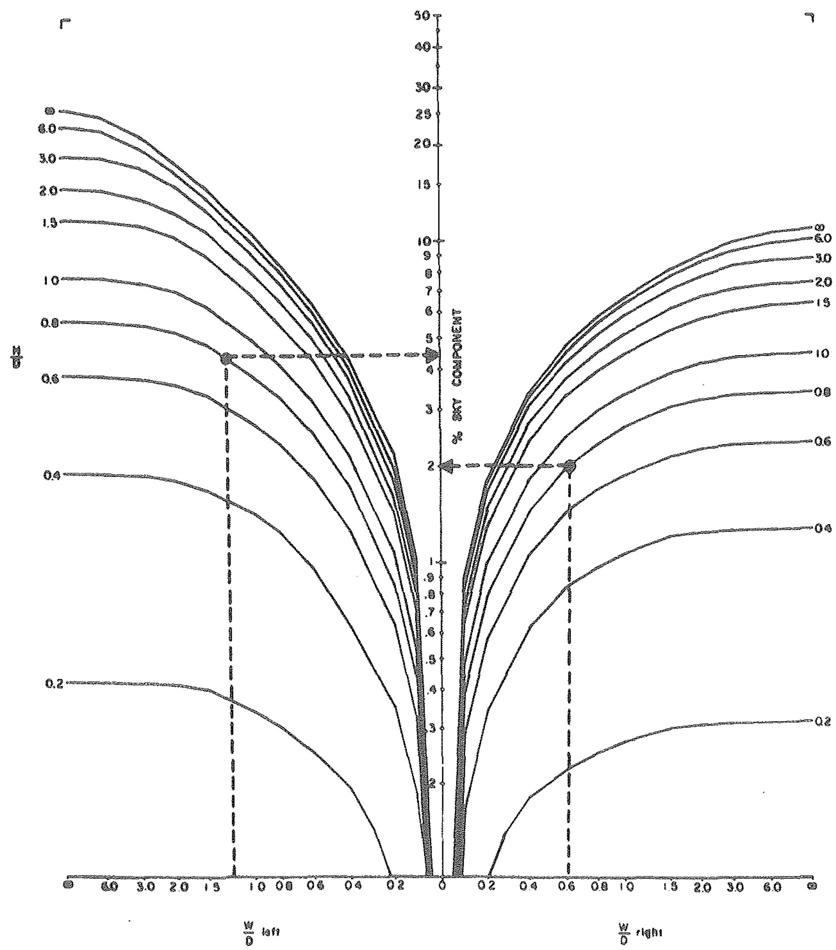

Fig. 7. Graph for determining sky component of daylight factor for clear sky conditions, sun altitude 40°. (XBL 803-8642)

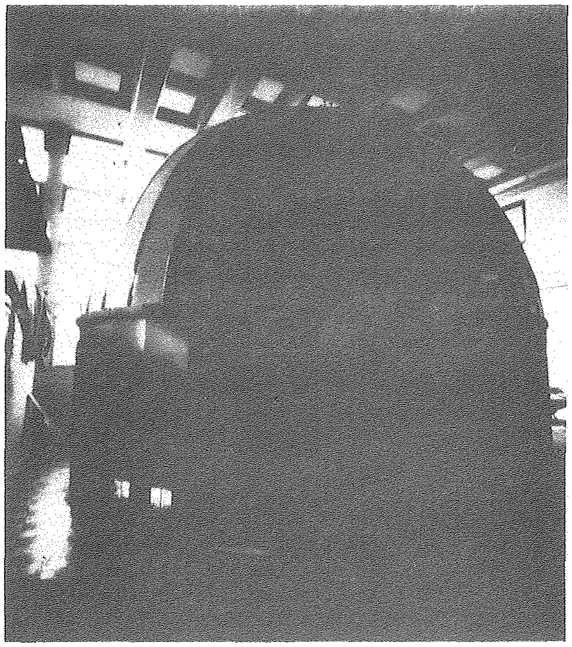

Fig. 8. Exterior view of artificial sky dome for daylighting studies. (CBB 803-2837)

the feasibility of using reflective devices mounted at the windows to take advantage of direct sunlight. In 1979, attention turned to using linear fresnel lenses as a possible alternative to mirror systems. Computer simulation and model testing in this area will continue in 1980.

We believe that daylighting techniques would be more widely used by architects and builders if technically accurate information was more accessible to them. For this reason, LBL has taken a lead role in developing a comprehensive educational program to fill this gap. A draft of our "Daylighting Resource Package," directed to educators and building designers and prepared in collaboration with the Illuminating Engineering Society, several universities, and daylighting experts throughout the country, will be available in summer, 1980. Over the next two years, the resource package will be refined, expanded, and disseminated widely.

Heat Mirror Commercialization. A transparent heat mirror is an optical coating applied to a glass or plastic glazing material that transmits the full solar spectrum but reflects long-wave infrared radiation emitted by room temperature surfaces. By reducing the radiative component of thermal losses, the heat transfer coefficient of a single- or double-glazed window is greatly reduced.

The development of transparent heat mirror coatings for plastic films has been successfully undertaken by subcontractors, although abrasion and corrosion resistance of the deposited coatings remains a problem area. It is possible that heat mirrors may find their first use in sealed airspaces of new windows rather than as retrofits to single-glazed windows, as originally envisioned. For new windows, the coating can be deposited directly on glass or on plastic films which are then glued to the glass surface or stretched across the double-glazed airspace.

We have examined various window configurations incorporating multiple glass, plastic and coating layers (Fig. 9). Note that the best of the heat mirror window systems has a U-value approaching that of a well-insulated wall. A number of prototype window systems incorporating heat mirrors in different configurations were fabricated and tested in our calibrated hot box. The experimental results agree well with our computational models. We are currently planning to install prototype windows incorporating heat mirrors in test buildings to monitor their performance under field conditions. In 1980, we expect that several firms may be ready to introduce these heat-mirror windows to the market.

Convection-Suppression Window Prototypes. Double-glazed windows frequently incorporate venetian blinds or similar devices between the glass panes to control light and glare as well as to provide privacy. These devices also help to reduce heat loss, although they have not been designed for that purpose. The Mechanical Engineering Department at the State University of New York, Stonybrook, is investigating the design and performance of mechanisms installed in the air space of double-glazed windows to suppress convective heat transfer (see Fig. 10). It appears that this modification of double-glazed windows may yield a heat-transfer rate approximating that of an insulated wall. Prototypes of such devices with a thermal resistance of R5 in an open mode and R10 in a closed mode have been built and tested. A heat-transfer gauge with a cross section of approximately 20 ft^2 was built so that full-sized windows could be tested. Interferometric techniques were used to examine heat transfer in the airspaces created by the parallel slats. Initially, ideal airspaces, i.e., with no air leaks, were examined. When the slat-to-glass clearance was increased to as much as 1/8 inch, the heat-transfer rate was not seriously increased. These results suggest that building products with a comparable level of thermal performance could be successfully manufactured.

Triple and quadruple glazing systems will further reduce heat loss through windows although solar gain may be sacrificed due to surface reflection losses. Replacing window glass with a thin plastic film coated to be anti-reflective solves this problem effectively. These lightweight, high-performance window systems have been studied by means of computer simulation, and prototypes tested in our laboratory show good agreement with the model. Although the performance of these systems does not match that of multi-glazed units incorporating transparent heat mirrors, they are not as susceptible to corrosion as units using heat mirrors.

	TOTAL GAP (cm)	ϵ	SURFACE	GAS	ΔT (K)	SOLAR TRANSMITTANCE	U ($W/m^2 \cdot K$)	CALCULATED OR MEASURED	SOURCE (Ref)
DOUBLE GLAZED WINDOW	.6	.055	3	Air	10	--	2.7	meas.	Glaser (19)
	1.2	.055	3	Air	10	--	1.8	meas.	Glaser
	1.2	.055	3	Krypton	10	--	1.0	meas.	Glaser
	1.6	.055	3	Air	10	.45 visible (est	1.6	meas.	Glaser
	2.0	.1	3	Air	20	.37 visible	1.5	calc.	Karlson & Ribbing (34)
	1.2	.15	3	Air	--	--	1.9	calc.	Rallio (16)
	1.27	.20	3	Air	22	.70	1.99	calc.	(ASHRAE Data)
	1.27	.05	3	Air	22	.63	1.70	calc.	(ASHRAE Data)
	1.2	.08 (est	3	Low Cond	--	.15-.49	1.4-1.5	meas.	Flachglas literature
	.64 - 1.27	low	3	Air	22	.04-.3	1.7-2.8	meas.	Commercially Available
	1.2	.1-.2	3	Krypton	19	--	.9	calc.	Koatlin (14)
	1.27	.05	3	Krypton	18	--	1.18	calc.	Silverstein (18)
DOUBLE GLAZED WITH SINGLE PLASTIC INSERT	3.6	.20	3,4	Air	--	.59	.89	calc.	Johnson (35)
	2.54	.05	4	Air	10	.56	1.19	calc.	
	1.8	.05	4	Air	10	.56	1.43	calc.	
	1.8	.05	4	Argon	10	.56	1.33	calc.	
	1.8	.05	4	Krypton	10	.56	.87	calc.	
	1.8	.20	4	Air	10	.63	1.60	calc.	
	2.54	.05	5	Air	10	.50	1.01	calc.	
	1.8	.05	5	Air	10	.50	1.25	calc.	
	1.8	.05	5	Argon	10	.50	1.15	calc.	
	1.8	.05	5	Krypton	10	.50	.72	calc.	
	1.8	.20	5	Air	10	.56	1.52	calc.	
DOUBLE GLAZED WITH DOUBLE PLASTIC INSERT	3.8	.05	7	Air	10	.46	.49	calc.	
	1.8	.05	7	Air	10	.46	1.24	calc.	
	1.8	.05	7	Argon	10	.46	.97	calc.	
	1.8	.05	7	Krypton	10	.46	.64	calc.	
	3.8	.05	3,6	Air	10	.42	.44	calc.	
	1.8	.05	3,6	Air	10	.42	1.24	calc.	
	1.8	.05	3,6	Argon	10	.42	.96	calc.	
	1.8	.05	3,6	Krypton	10	.42	.61	calc.	

Fig. 9. Thermal performance characteristics of various high performance window designs. (XBL 796-10098)

<u>Movable Insulation</u>. We have calculated and measured the thermal performance of a large number of movable insulation systems for windows. (Some results are described in the Analysis and Computer Modeling Section.) Calculations and laboratory measurements are now being supplemented with large-scale field testing of products in buildings.

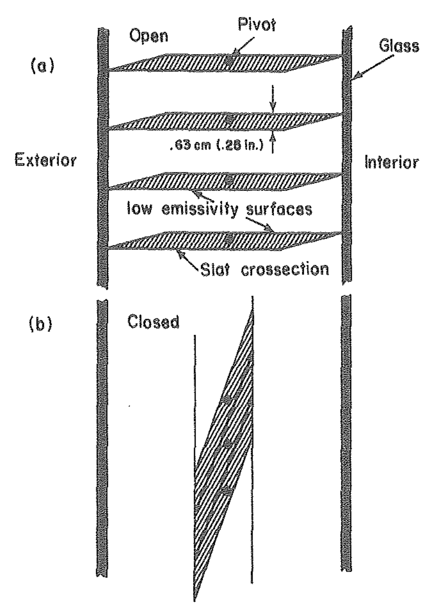

Fig. 10. Schematic cross-section of open and closed convection suppression window prototype. (XBL 796-1099)

The Insulating Shade Company in Branford, CT, has developed a multilayer, aluminized plastic roll-up shade with a thermal resistance of 12 in its deployed mode (Fig. 11). Two hundred such shades have been installed in a college dormitory, and energy savings are being monitored by means of a data-acquisition system designed and built at LBL. Patterns of occupant use of these shades will be studied and attempts may be made to motivate occupants to use the insulating devices more effectively.

<u>Selective-Reflectance Coatings</u>. Reflective and/or tinted glass is widely used in many commercial buildings to reduce solar impact and, thus, energy requirements for air conditioning. However, this glazing will also reduce the amount of daylight illuminating interior spaces and thus increase energy used for electrical lighting.

Since approximately one-half of the sun's radiation is short-wave infrared, which contributes nothing to illumination, an optical coating that selectively reflects this infrared but transmits visible light could, ideally, reduce cooling loads by 50% without reducing available illumination. Under subcontract, Kinetic Coatings, Inc., has used novel ion-beam sputtering techniques to produce durable, weather-resistant selective coatings that can be applied to the outside of a window where they function effectively in a solar-control mode. A wide range of selective-reflectance coatings and protective layers has been produced and tested for both optical performance and weatherability (Fig. 12). In 1979, Kinetic Coatings, Inc., focussed their efforts on scaling-up the sputtering deposition system to provide coating uniformity over a larger sample size. Results to date show a uniformity of ± 5% in optical properties over a

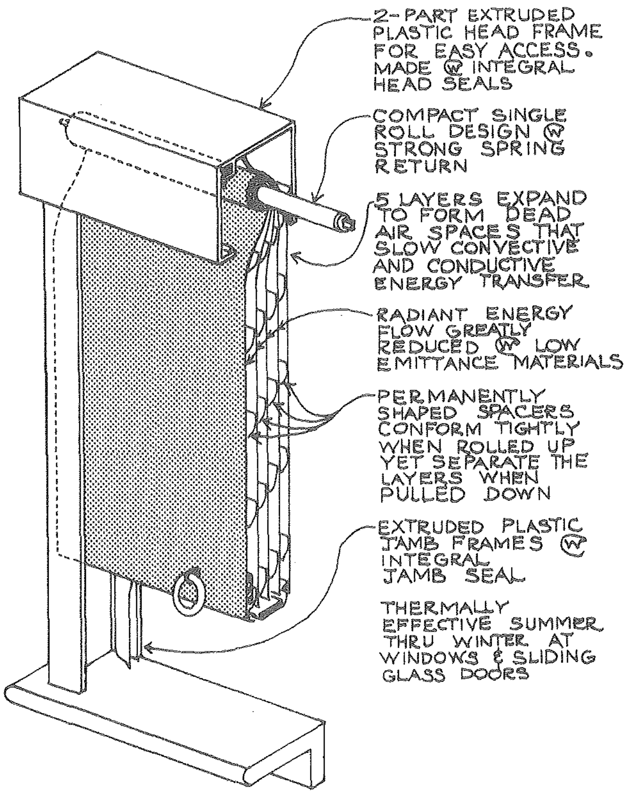

Fig. 11. Cross-section of multilayer insulating window shade. (XBL 803-8641)

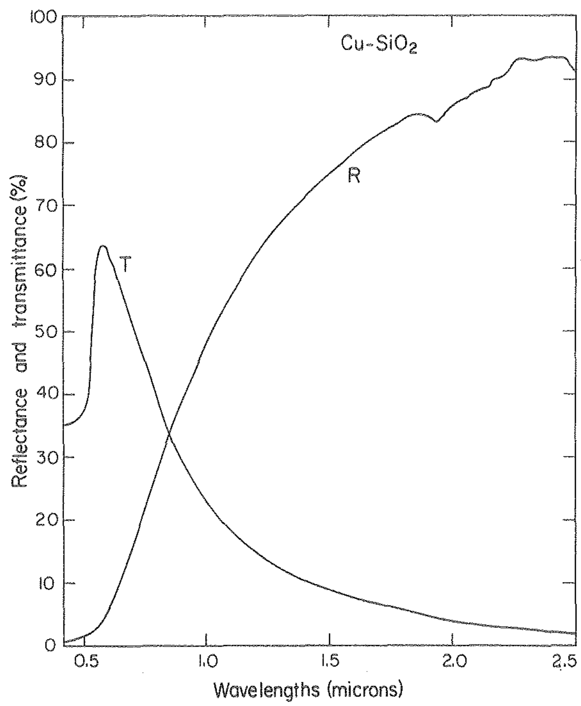

Fig. 12. Normal spectral transmittance and reflectance of selective solar control film with increaed visible transmittance; glass substrate (1/8") - Cu (78A) - SiO_2 (500A); weighted spectral averages, T solar = 42%, T visible = 60%. (XBL 792-512)

1.5 ft^2 area. Indications are that these methods can be further refined so that glass of architectural size can be coated with equal or better uniformity.

High-Performance Sun Control Systems. Conventional venetian blinds are reasonably successful in reducing solar heat gain through windows. To improve their performance, Stevens Institute of Technology in Hoboken, NJ, is testing and evaluating a new class of highly reflective venetian blinds expected to transmit 50% less summer heat than conventional blinds. Test results from this program will be compared with existing methods of calculating the performance of blinds.

Air-Flow Window Systems. Among the options being studied for high-performance window systems are those designed to control heat transfer by using air flow between multiple panes of glazing. These systems offer thermal performance advantages in winter (by reducing net heat losses through the windows and collecting useful solar gain) and in summer (by reducing cooling loads) without sacrificing daylighting potentials year-round.

One such window system of interest to our program is the "Clearview" solar-collector window developed by researchers at the Environmental Research Laboratory (ERL) at the University of Arizona. Designed for residential applications, this window system is being analyzed in detail by ERL for its performance capabilities, and will be field-tested in the upcoming heating and cooling season.

Another approach to designing air-flow windows has been used in Europe for many years. Windows are constructed with cavity ventilating ports that permit air to pass between double or triple glazing at rates controlled by HVAC system pressures (Fig. 13). Venetian blinds in the glazing cavity absorb the sun's heat in the winter and the air flow over the blinds carries the heat throughout the building. Similarly, the heated air can be exhausted from the building in summer to reduce cooling loads. This approach lends itself to many different system configurations that will be investigated by the University of Utah under subcontract. The performance of exhaust air windows and conventional multiple glazed windows will be compared, side-by-side, in a test building designed to rotate so that all window orientations can be evaluated. Test results will be used to assess their marketability in the United States.

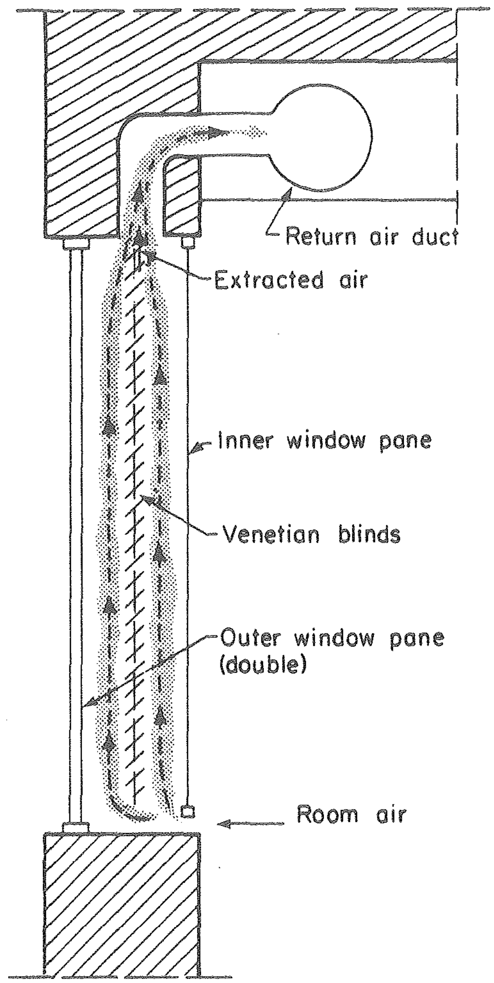

Fig. 13. Schematic cross-sections for air-flow window system. (XBL 7912-13366)

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